LUXTERA
FIBER TO THE CHIP

The Luxtera EPIC Program

"Electronic and Photonic Integrated Circuits"

March 5, 2007

Cary Gunn
CTO, Co-founder

Report Documentation Page

Form Approved
OMB No. 0704-0188

1. REPORT DATE	2. REPORT TYPE	3. DATES COVERED
05 MAR 2007	**N/A**	**-**

4. TITLE AND SUBTITLE	5a. CONTRACT NUMBER
Electronic and Photonic Integrated Circuits	5b. GRANT NUMBER
	5c. PROGRAM ELEMENT NUMBER
6. AUTHOR(S)	5d. PROJECT NUMBER
	5e. TASK NUMBER
	5f. WORK UNIT NUMBER
7. PERFORMING ORGANIZATION NAME(S) AND ADDRESS(ES) **Luxtera, Inc.**	8. PERFORMING ORGANIZATION REPORT NUMBER
9. SPONSORING/MONITORING AGENCY NAME(S) AND ADDRESS(ES)	10. SPONSOR/MONITOR'S ACRONYM(S)
	11. SPONSOR/MONITOR'S REPORT NUMBER(S)

12. DISTRIBUTION/AVAILABILITY STATEMENT
Approved for public release, distribution unlimited

13. SUPPLEMENTARY NOTES
DARPA Microsystems Technology Symposium held in San Jose, California on March 5-7, 2007. Presentations, The original document contains color images.

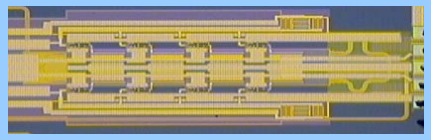
14. ABSTRACT

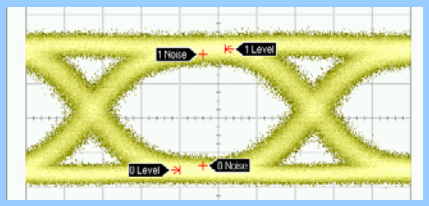
15. SUBJECT TERMS

16. SECURITY CLASSIFICATION OF:			17. LIMITATION OF ABSTRACT	18. NUMBER OF PAGES	19a. NAME OF RESPONSIBLE PERSON
a. REPORT **unclassified**	b. ABSTRACT **unclassified**	c. THIS PAGE **unclassified**	**UU**	**33**	

Luxtera CMOS Photonics Technology

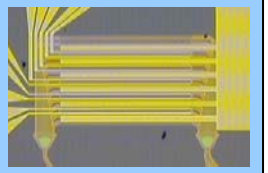
Silicon 10G Modulators
driven with on-chip circuitry
highest quality signal
low loss, low power consumption

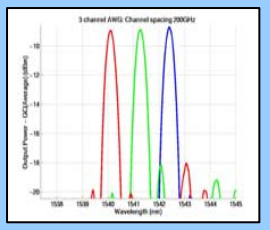




Flip-chip bonded lasers
wavelength 1550nm
passive alignment
non-modulated = low cost/reliable

Silicon Optical Filters - DWDM
electrically tunable
integrated w/ control circuitry
enables >100Gb in single mode fiber





Complete 10G Receive Path
Ge photodetectors
trans-impedance amplifiers
output driver circuitry

Fiber cable plugs here

Ceramic Package

The Toolkit is Complete
✓10Gb modulators and receivers
✓Integration with CMOS electronics
✓Cost effective, reliable light source
✓Standard packaging technology

Trailblazer in Silicon Photonics

- **Mission:**
  - Deliver photonic solutions manufactured in a mainstream CMOS fabrication, test and assembly processes to provide customers with high performance optical solutions at price points traditionally associated with copper
- **Funded:** November 2001
- **Location:** Carlsbad, CA
- **Staff:** 57
- **Top Tier Investors:**
  - August Capital
  - New Enterprise associates
  - Sevin Rosen Funds
  - Three Corporate Investors
- **Intellectual Property:**
  - >100 Patents Filed For
  - 40 Issued

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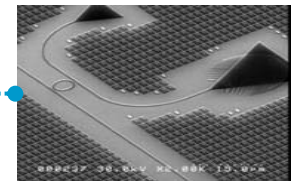
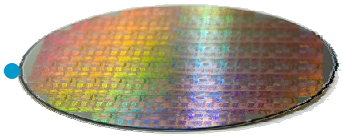
Unbroken String of Industry's Firsts

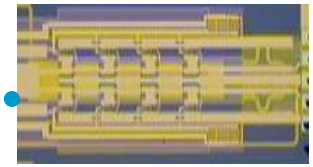
- **2001** – The first CMOS waveguide and Fiber-to-the-Chip Coupler



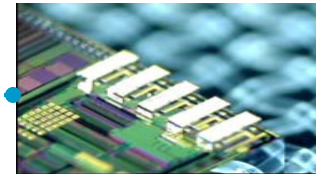
- **2002** – The first CMOS photonics in standard 130 nm SOI-CMOS process



- **2003** – The first CMOS 10G Modulator

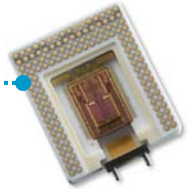


- **2004** – First Laser bonded to a CMOS die

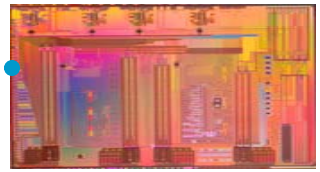


- **2005** – First wafer scale optical probing

- **2005** – First single chip dual XFP transceiver



- **2006** – First monolithic CMOS 4x10G WDM



- ***2007 – Major announcements coming…***

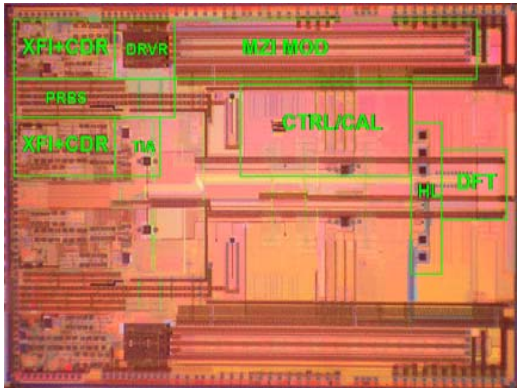
?

CMOS Photonics Foundry

- Luxtera uses FSL's 0.13µm SOI process
  - Same process used to construct their PowerPC™ embedded microprocessors
  - Very high yield, high volume, mature process
- Design environment is Cadence at the system/subsystem level
  - Device design done on 200 node cluster running 3D FDTD
  - Can perform LVS, DRC on optical circuits
- Philosophy: Started with existing electronics design manual, and make the optics fit – requires extensive characterization, simulation, compromise
  - ~80 films in a CMOS process, need to understand optical properties of ALL of them

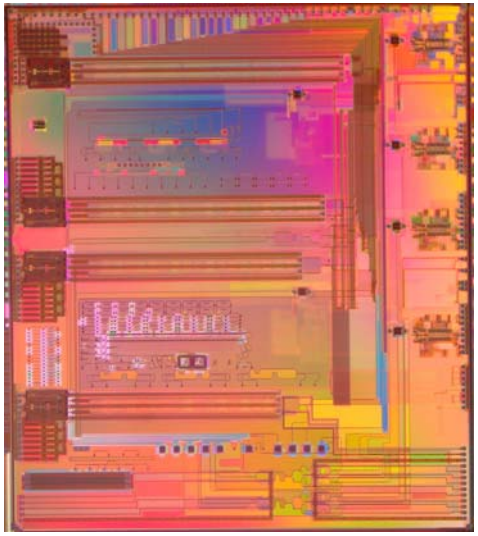
Example CMOS Photonics Chips:

Aurora



Two independent 10Gb transceivers on a single die (contains complete PHY circuitry)

Pulsar



A single 40Gb WDM transceiver
4λ x 10Gb
(PMD circuits only)

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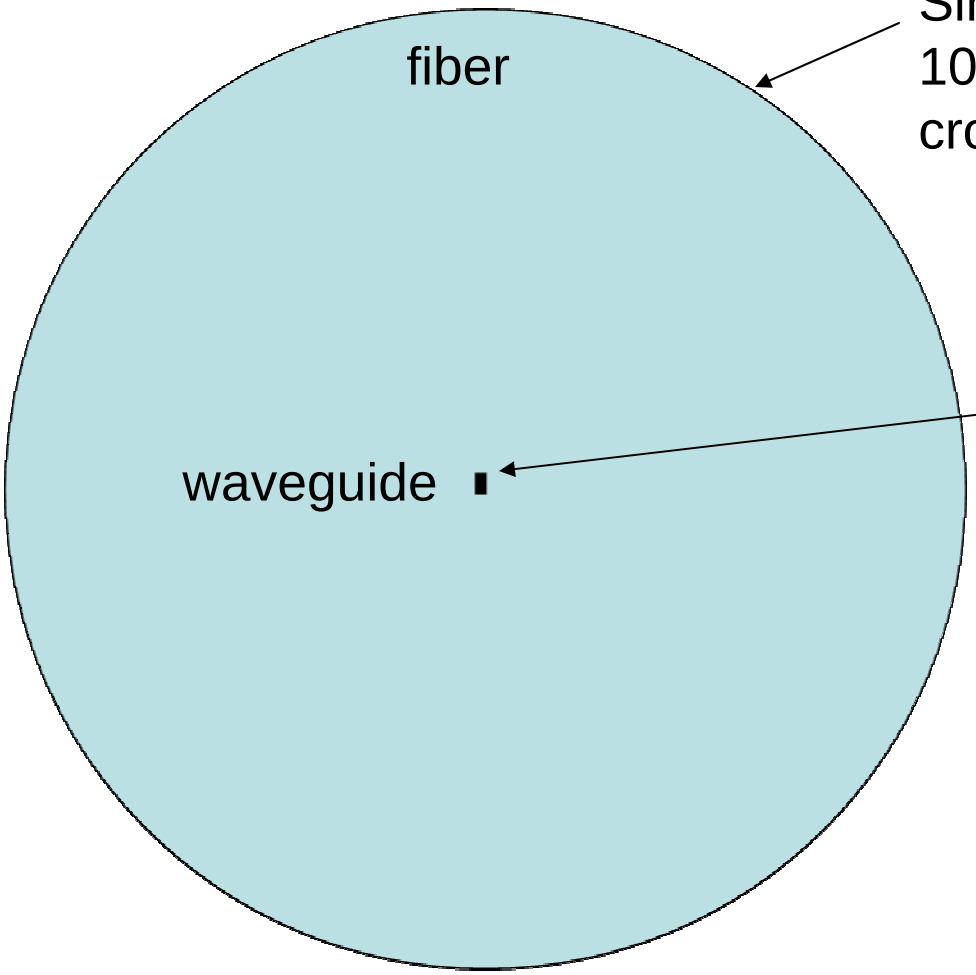
Component Level Technology

The fiber coupling problem

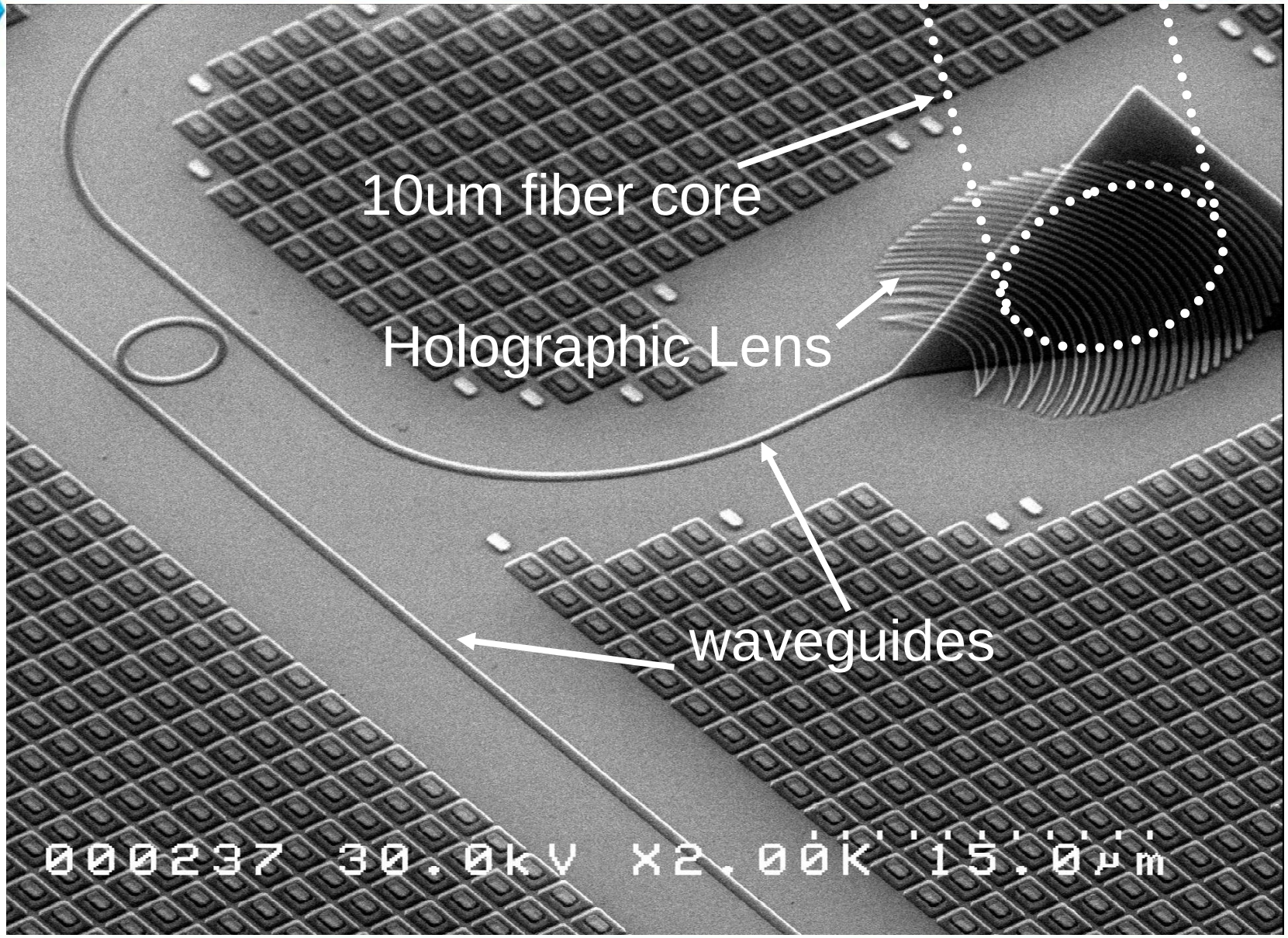


Single mode fiber has
10µm diameter core,
cross section of 80µm²

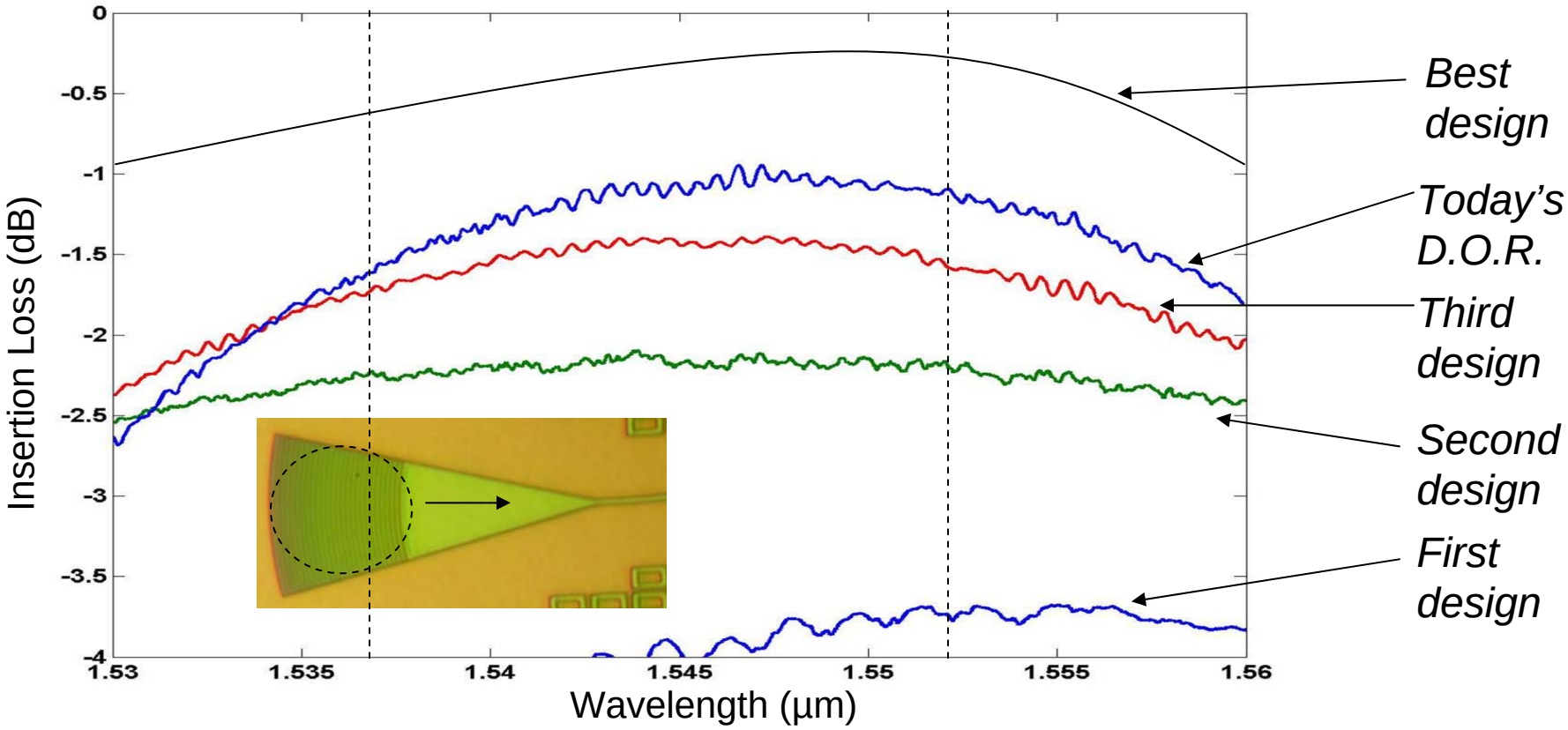
A “good” SOI waveguide
has cross sectional area
of 0.1µm²

Coupling efficiency is approx.
the ratio of the areas:
0.1/80 = 0.1% (-30dB)

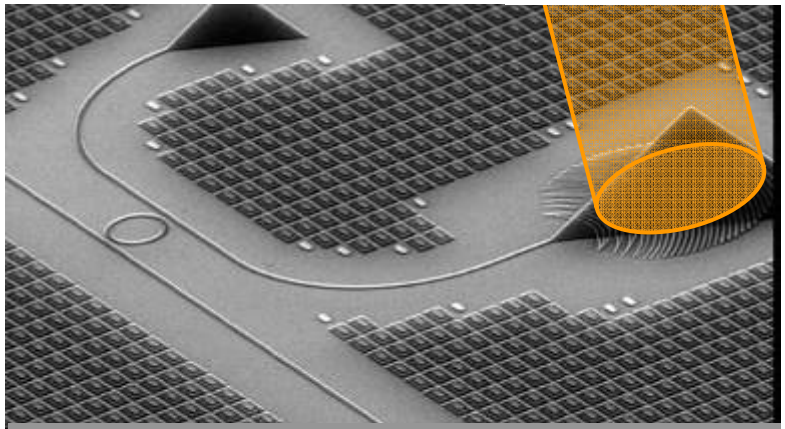
Better than 50% (-3dB) desired


10um fiber core
Holographic Lens
waveguides
000237 30.0kV X2.00K 15.0µm

Holographic Lens Evolution



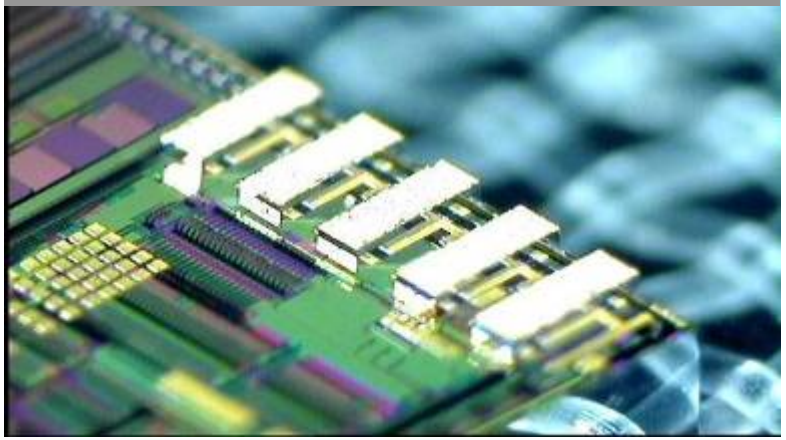
Luxtera's key to Fiber-to-the-chip: connecting the micro and nano scales



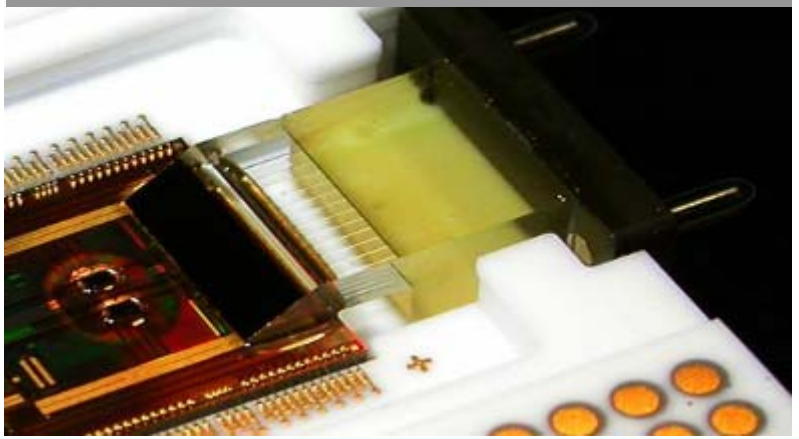
Vertical optical coupling enables…

Wafer-scale testing

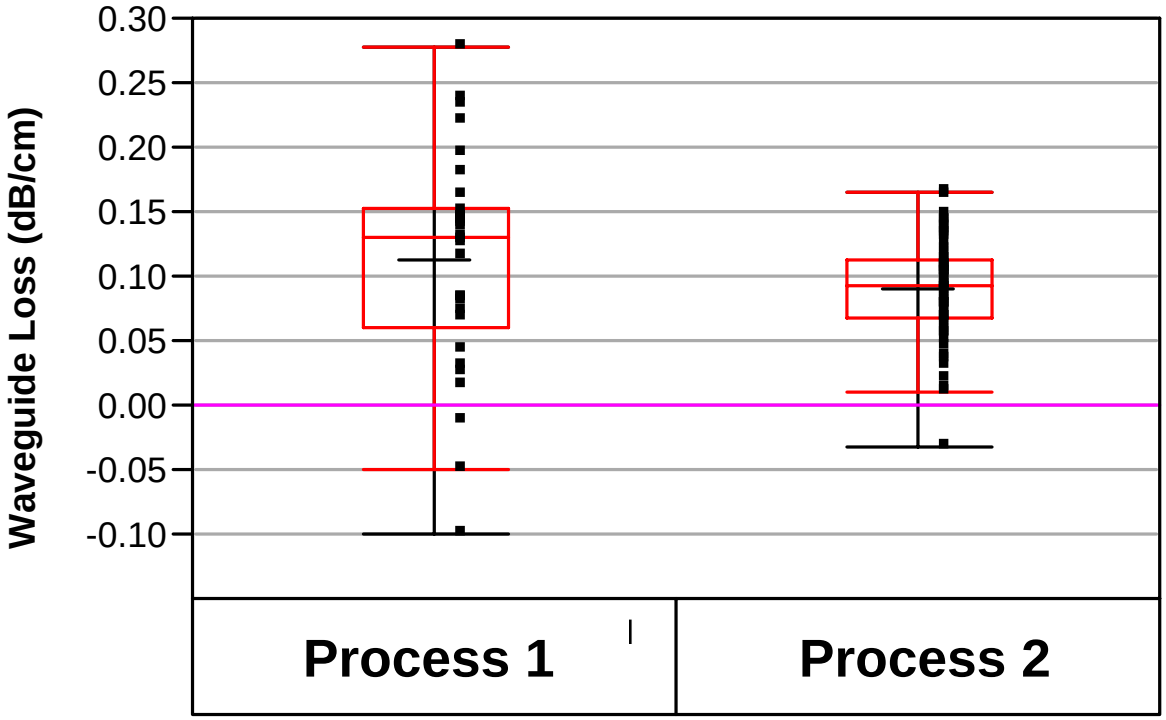
Flip-chip mounted lasers

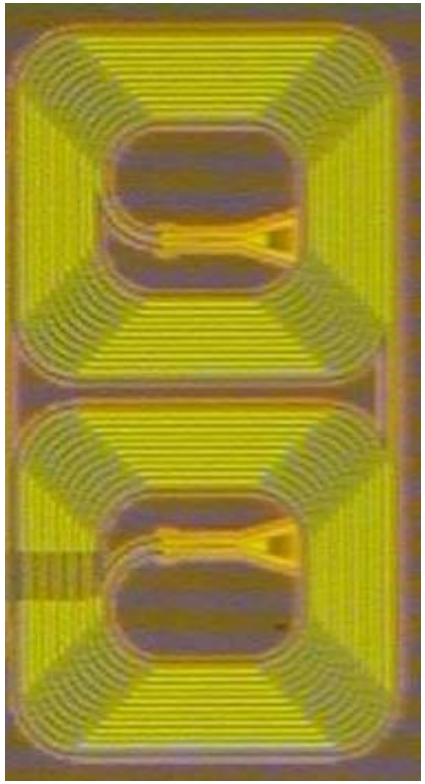


Low cost Fiber to the Chip attach



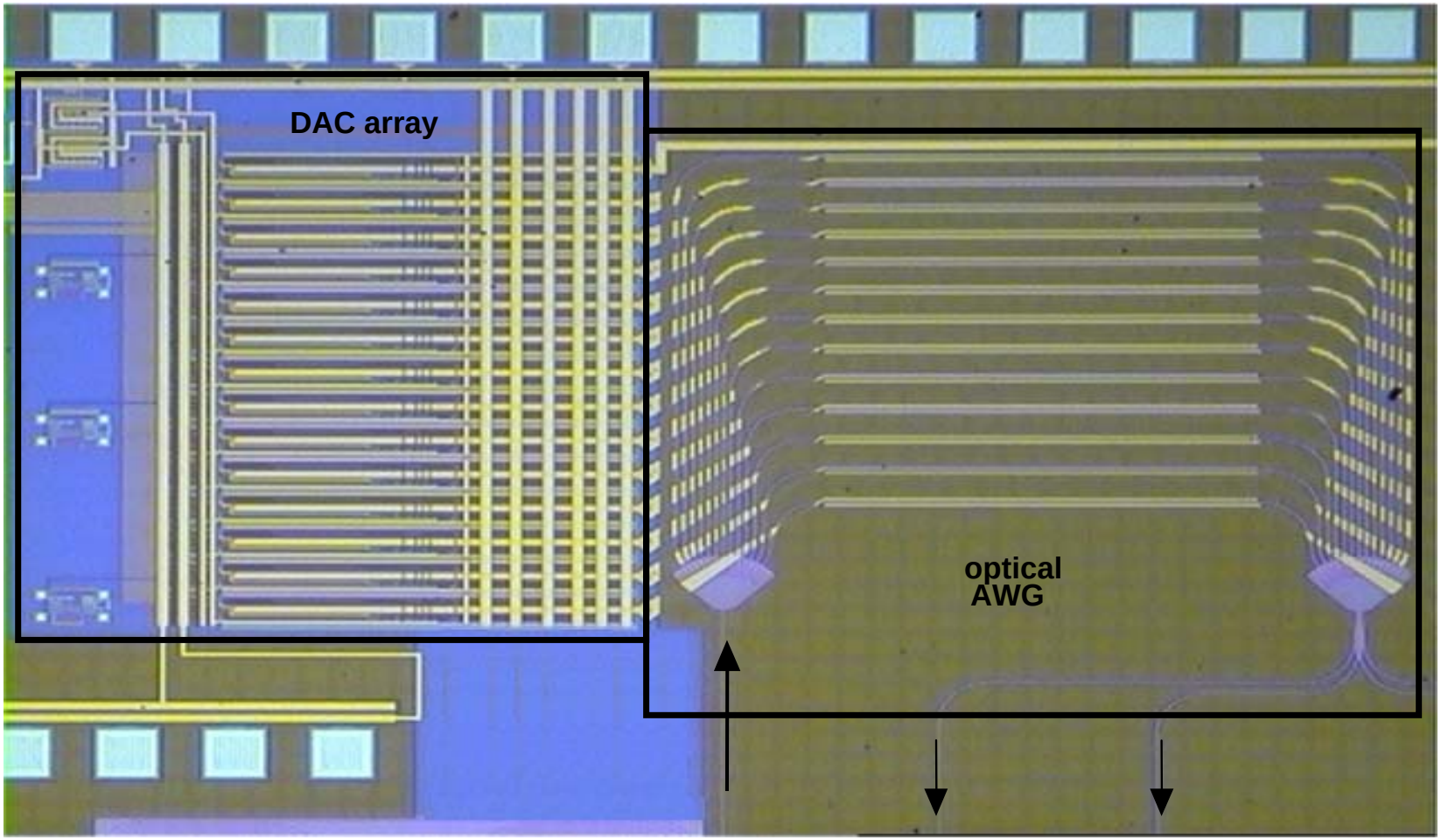
Routing - Waveguide Loss



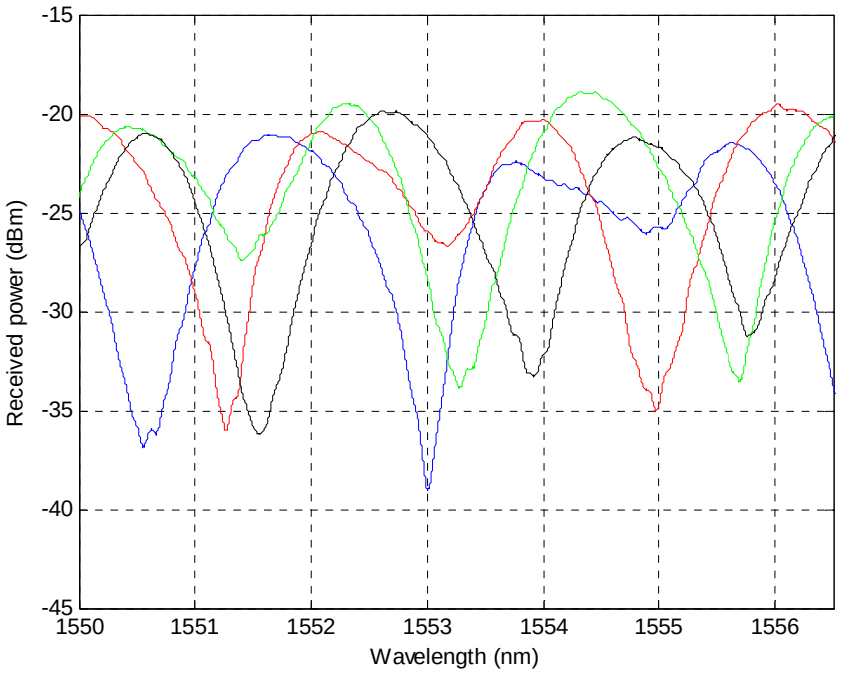


Waveguide Loss no longer a major issue

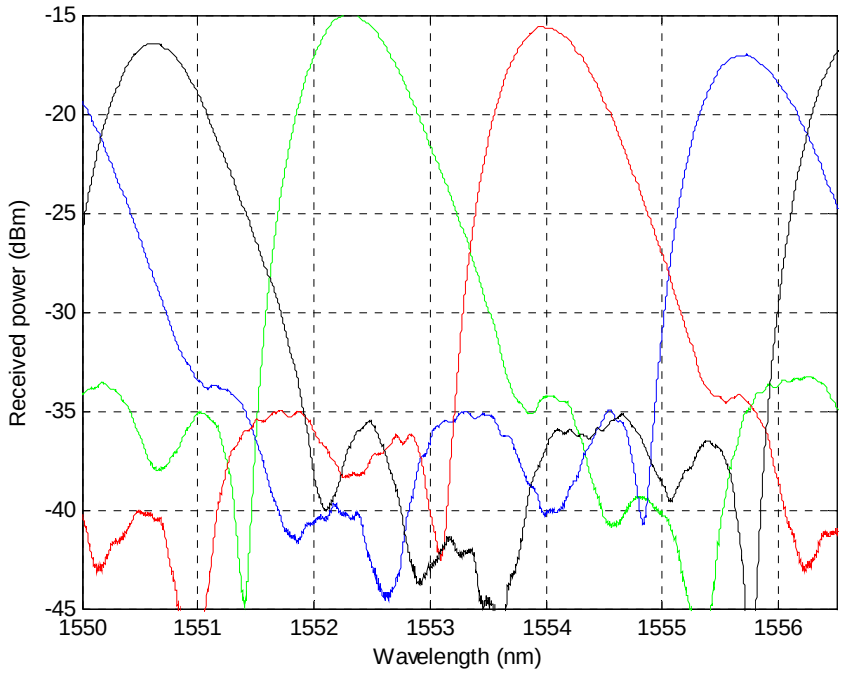
Electrically Tunable Arrayed Waveguide Grating (AWG)



Electrically tunable AWG results

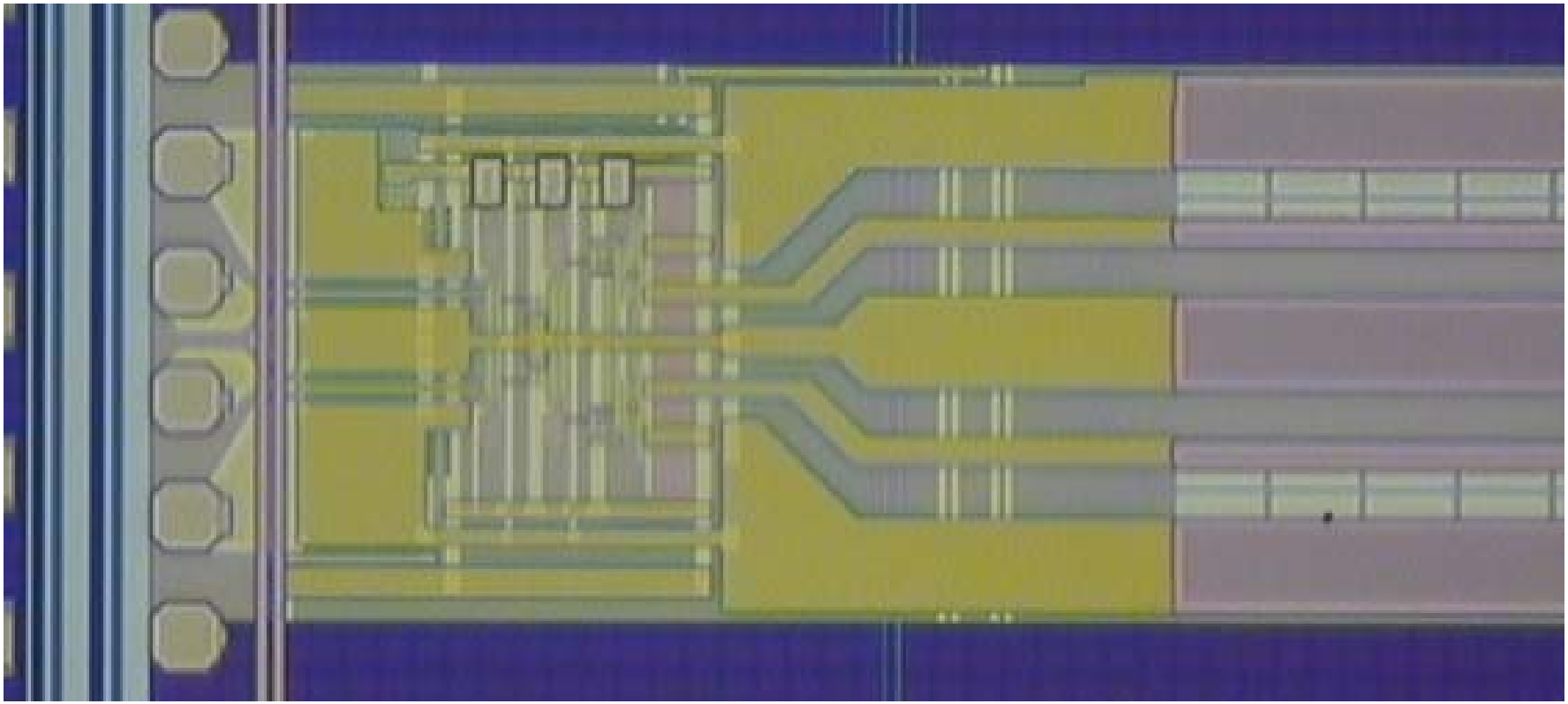


BEFORE TUNING



AFTER TUNING

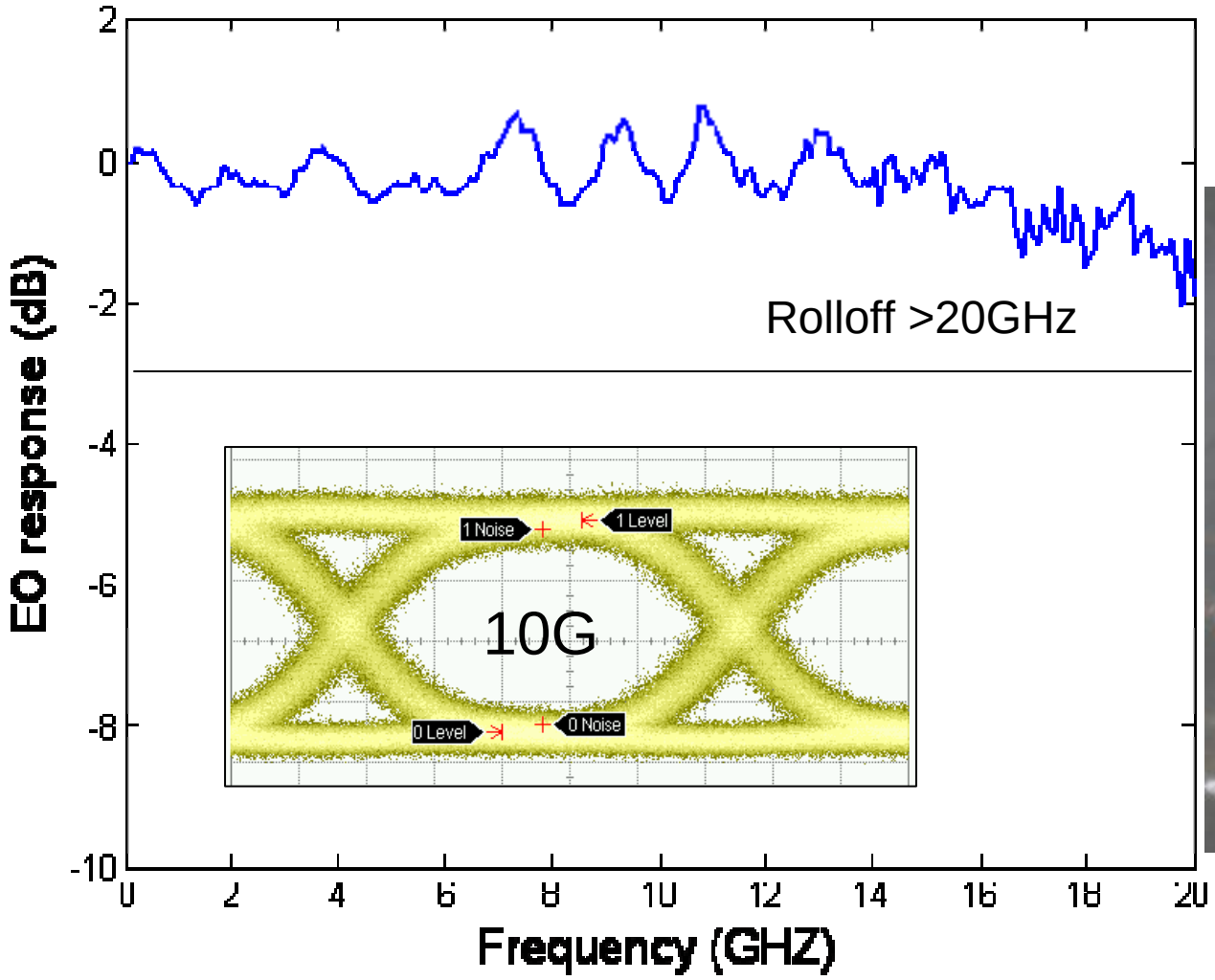
Modulator with integrated driver

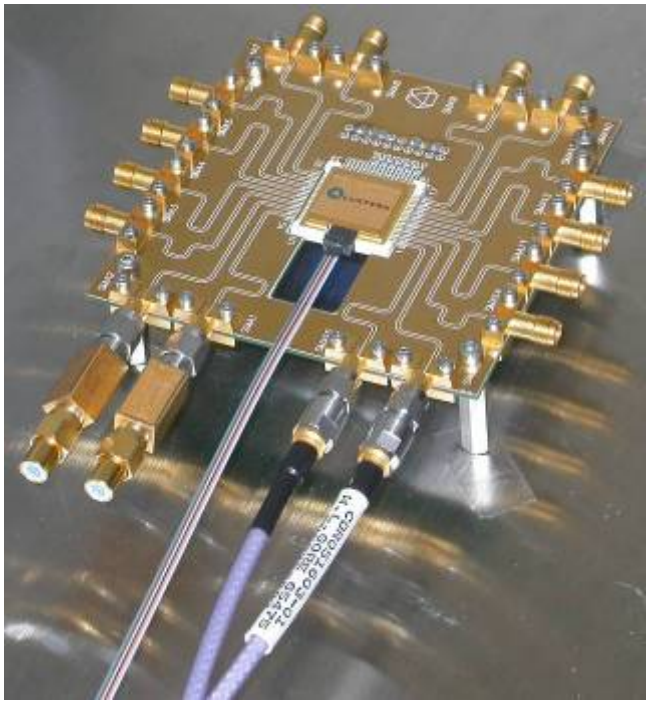


CMOS Optical Modulator with Differential Driver

ISSCC 2006, A Huang, et al.

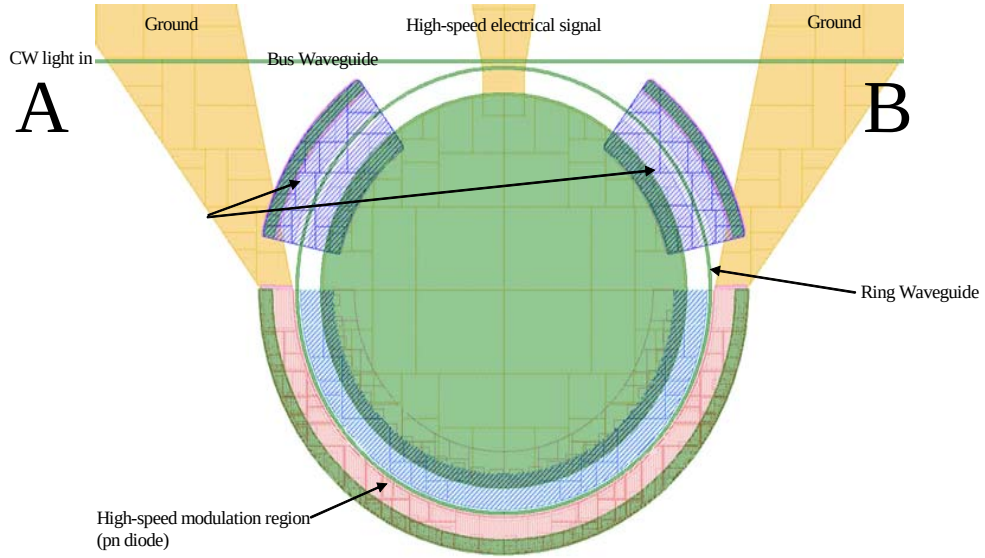
CMOS Optical Modulator Performance



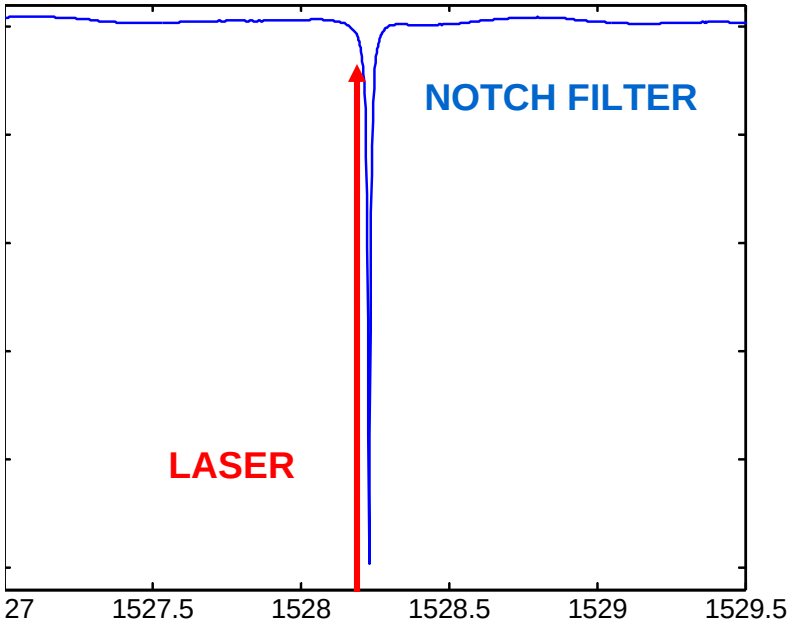


Second Generation Technology

Ring modulators = high density/bandwidth

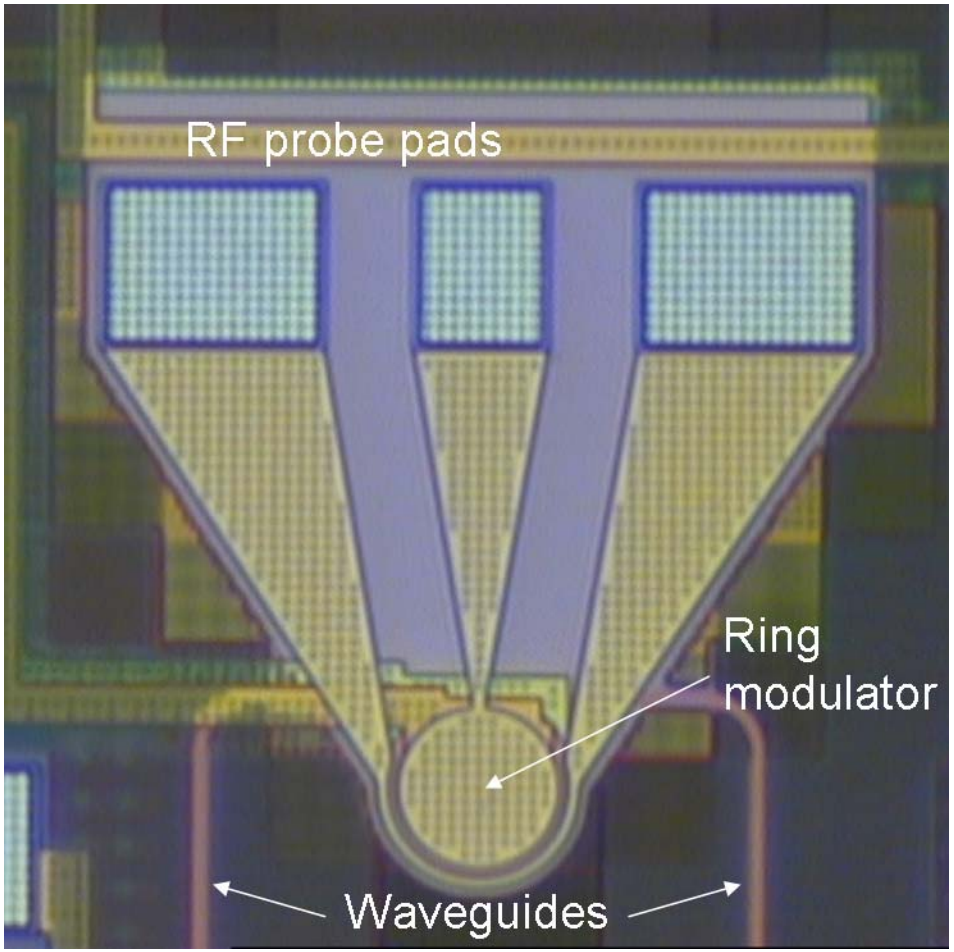


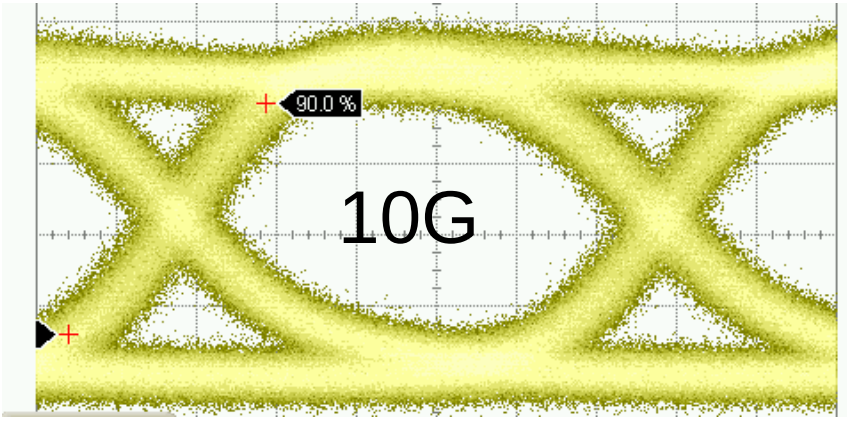
Transmission A-> B

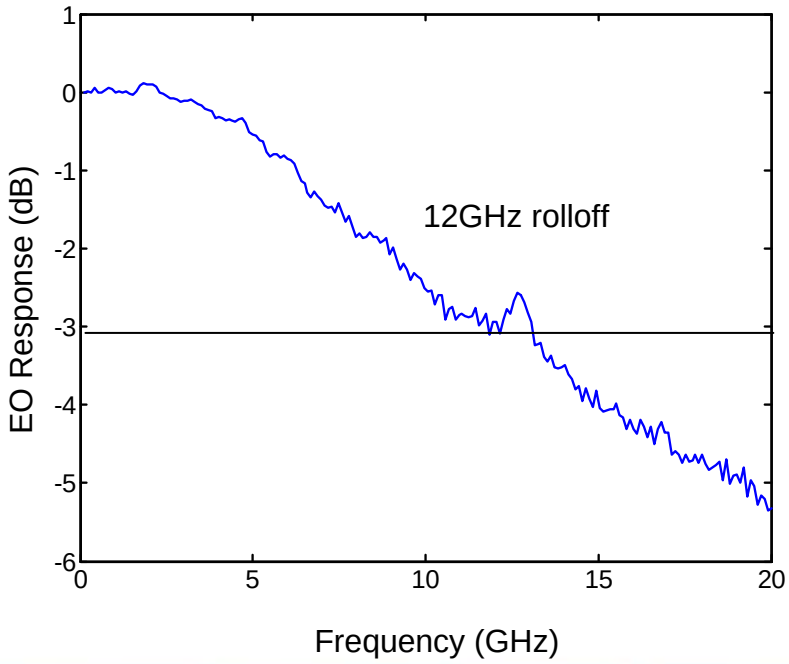


- 30 um radius ring
- Many Tb per mm²
- 2000x smaller than electronic PHY

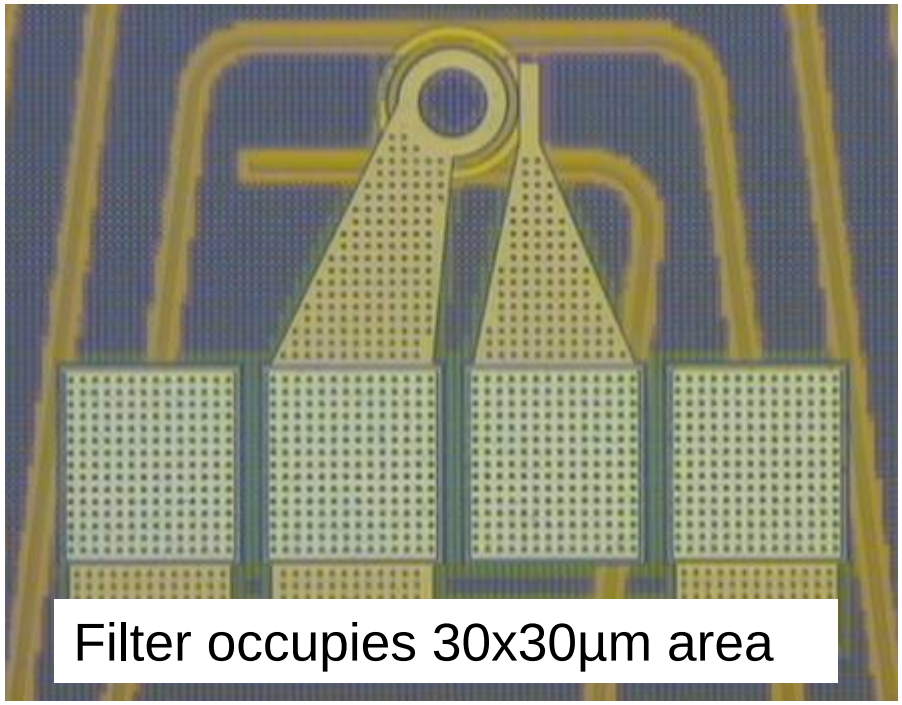
Ring Modulators Work at 10G

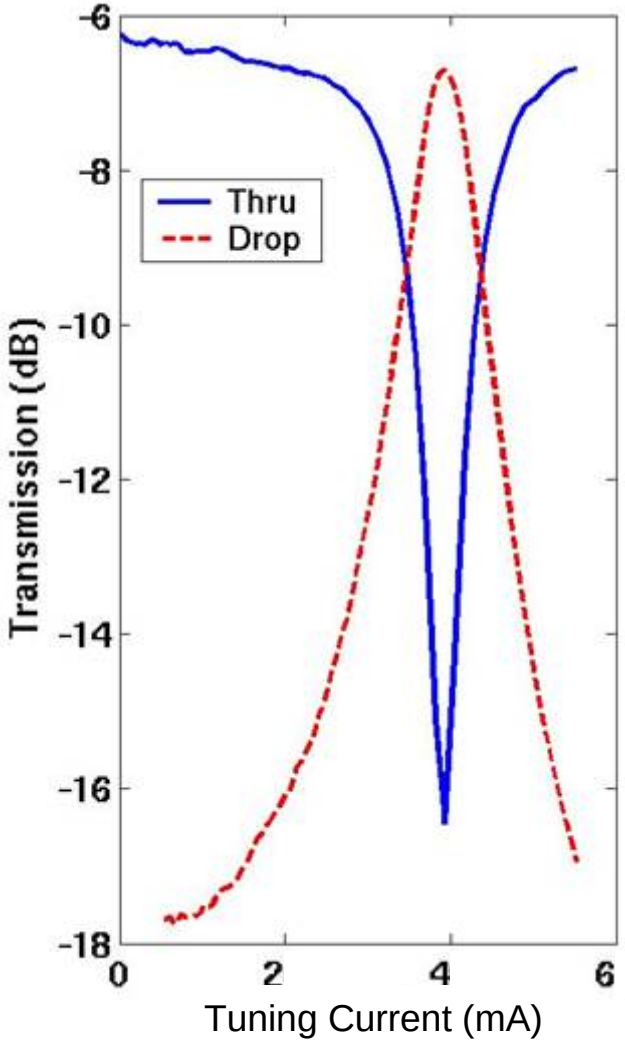






Small Tunable Optical Filter for WDM





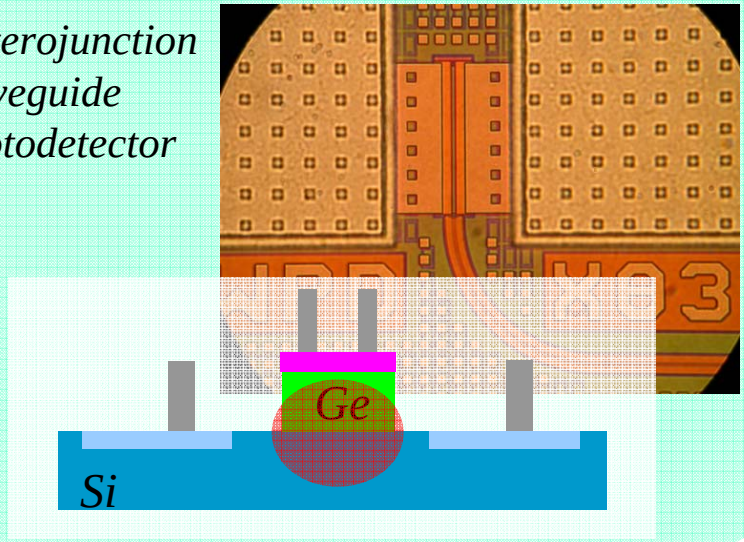
Tunable filters allow:

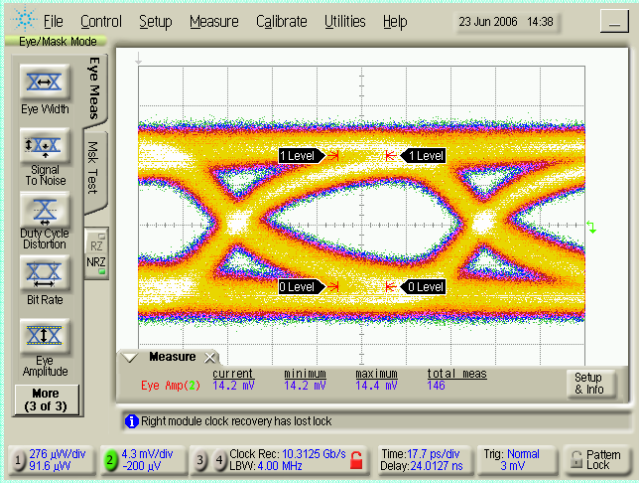
Dynamic reconfiguration

Operation over wide temperature range

Ge detectors at 10Gbps

Heterojunction waveguide photodetector





Eye diagram at 10Gb/s, 1550nm, 3V reverse bias, no TIA

Low speed device

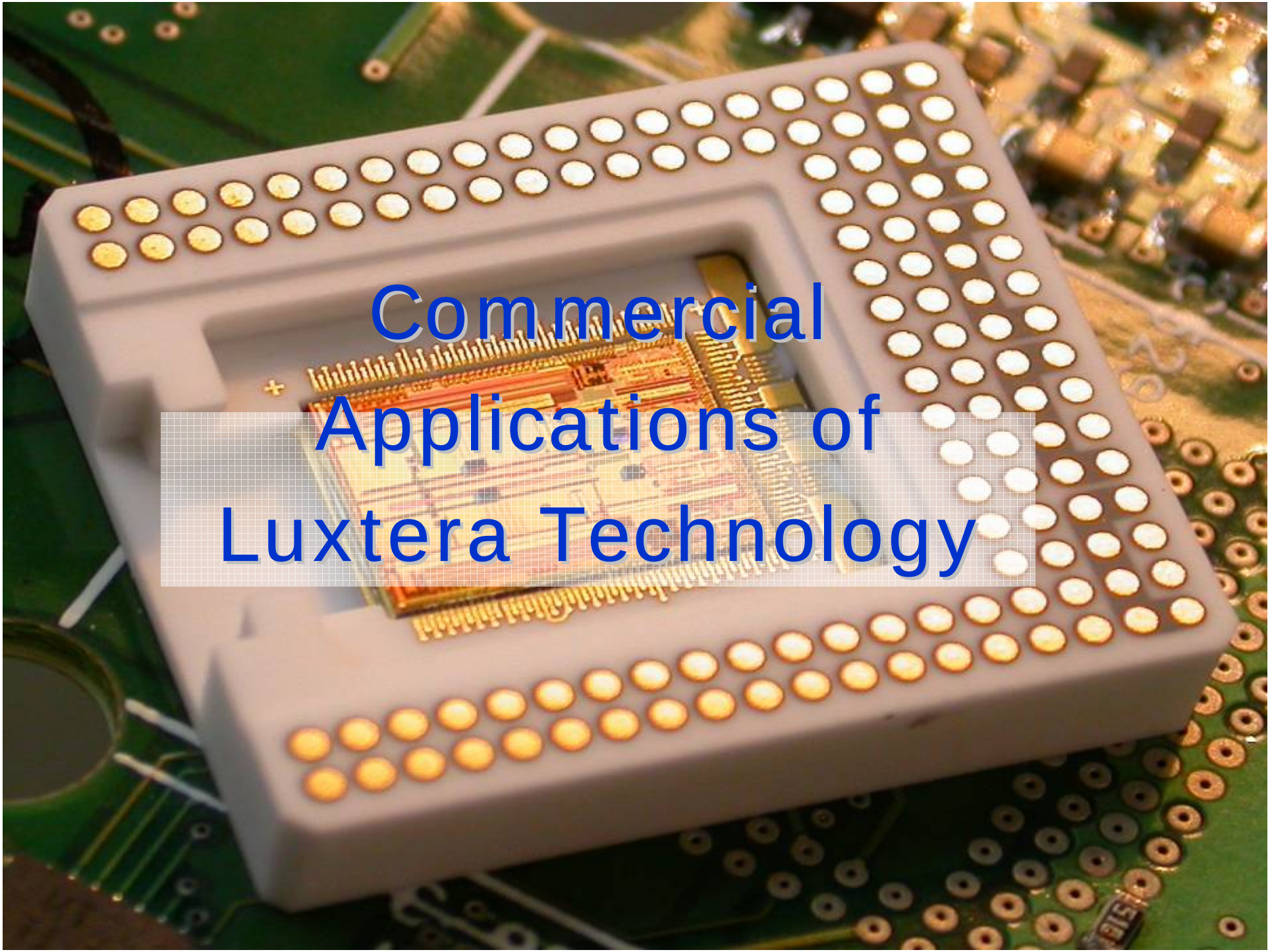
Typical performance @ 50C, 1550nm, 3V reverse bias

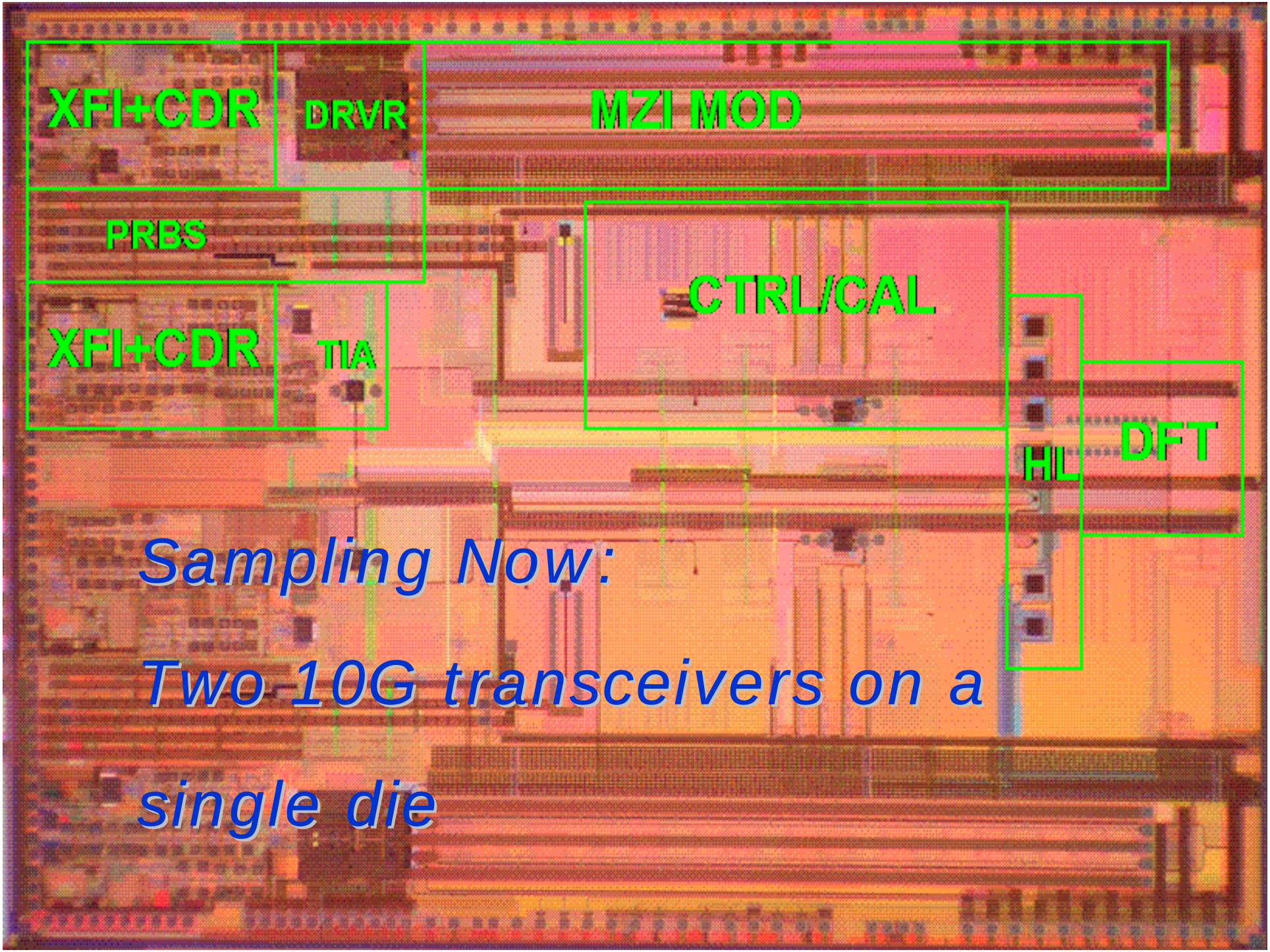
Responsivity	*0.4A/W*
Dark current	*3nA*
Bandwidth	*5 GHz*

High speed device

Typical performance @ 50C, 1550nm, 3V reverse bias

Responsivity	*0.5A/W*
Dark current	*30uA*
Capacitance	*30fF*
Bandwidth	*14 GHz*

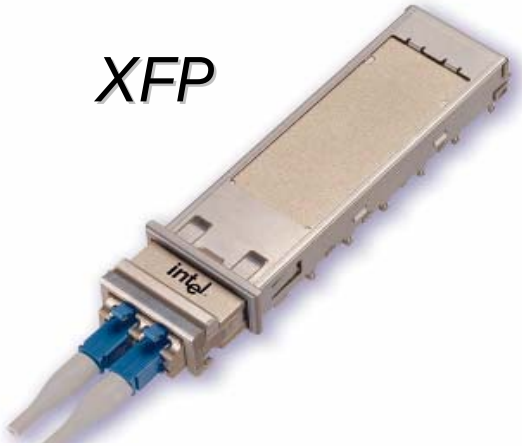

Commercial
Applications of
Luxtera Technology


XFI+CDR
DRVR
MZI MOD
PRBS
CTRL/CAL
XFI+CDR
TIA
HL
DFT
Sampling Now:
Two 10G transceivers on a
single die

Aurora – the First Product

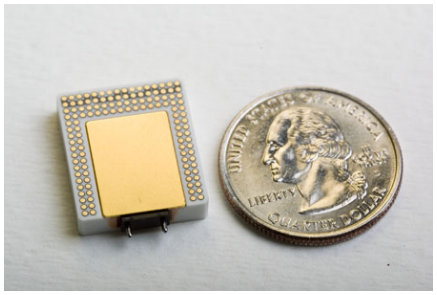
2 XFP Modules in a single Chip

XFP



XFP

Aurora

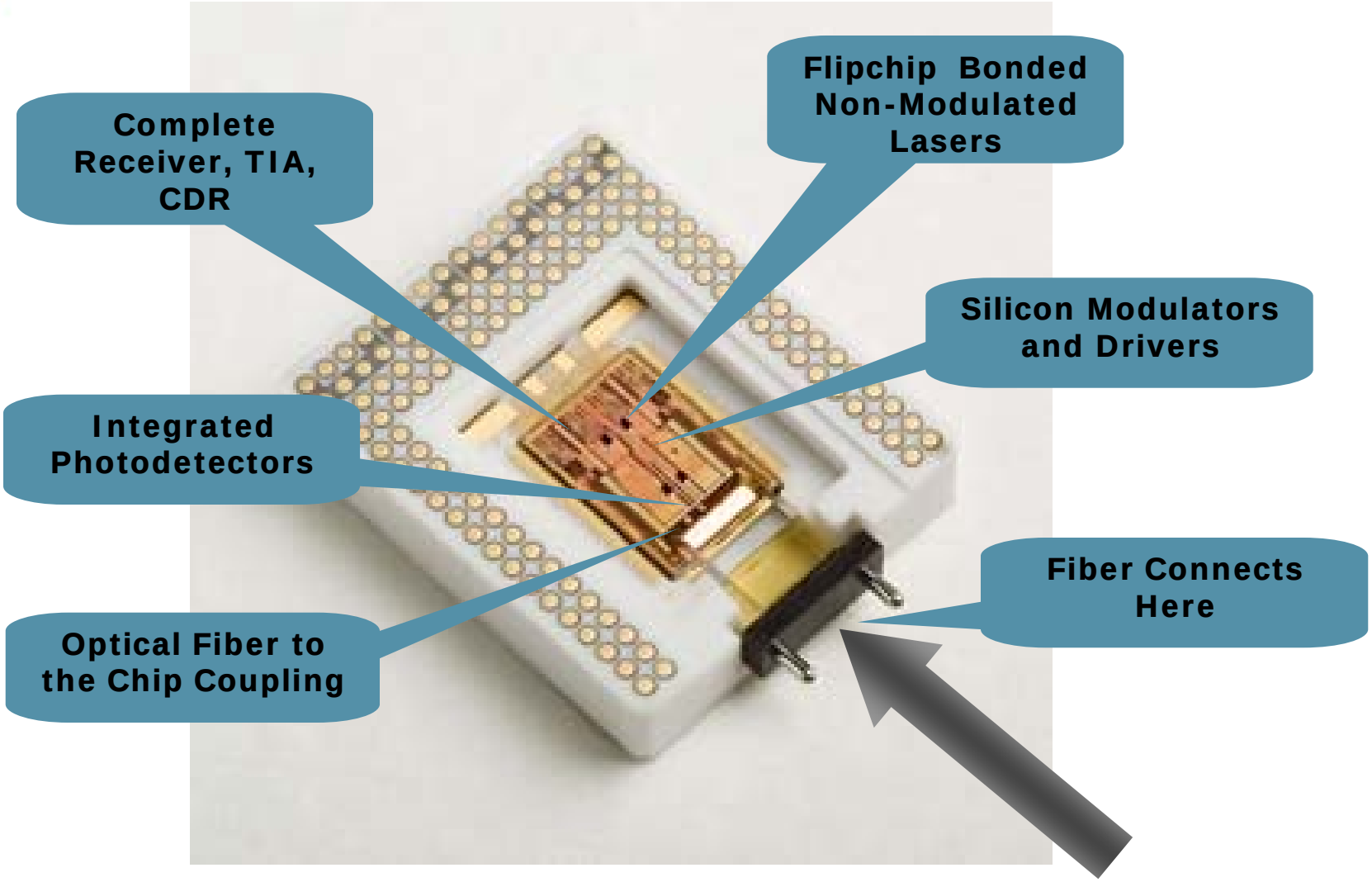


¼ size of XFP

Over 50% lower cost

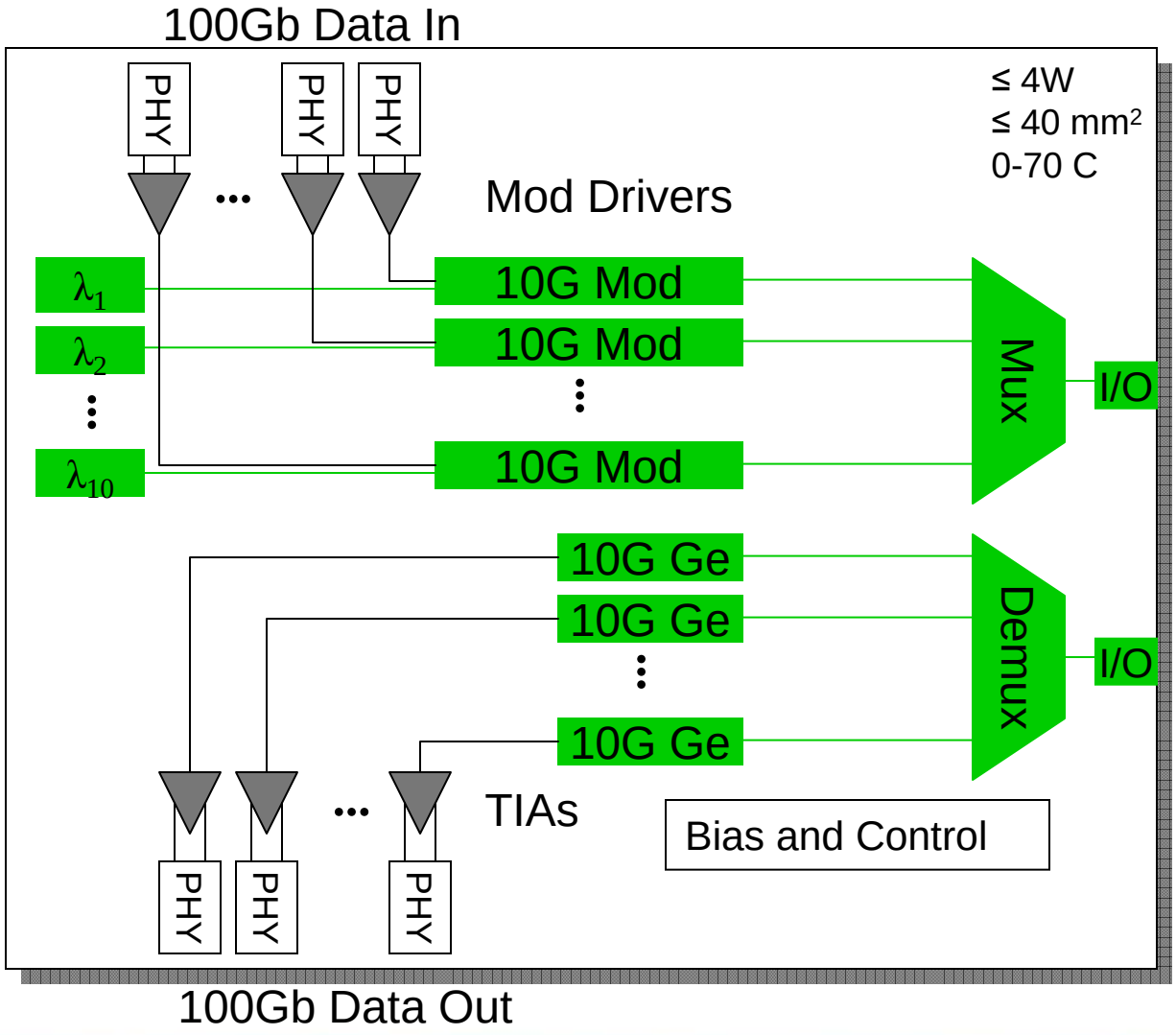
Up to 2,000m reach

XFP compliant management


Complete Receiver, TIA, CDR
Flipchip Bonded Non-Modulated Lasers
Silicon Modulators and Drivers
Integrated Photodetectors
Fiber Connects Here
Optical Fiber to the Chip Coupling

EPIC Program Progress – Multiwavelength Transceivers

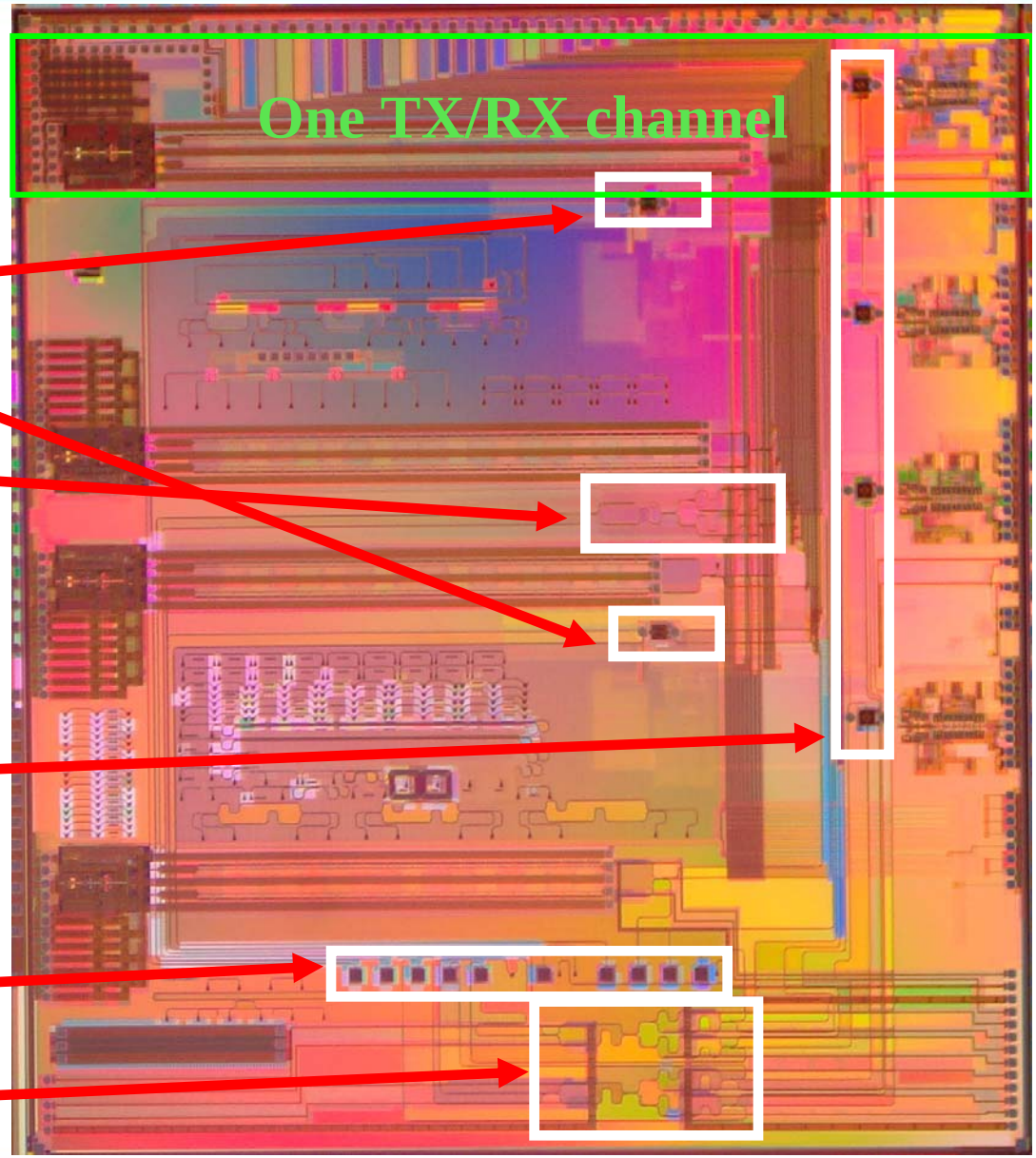
100Gb Transceiver – Prototypes Oct 2008



TX Fiber – 100Gb

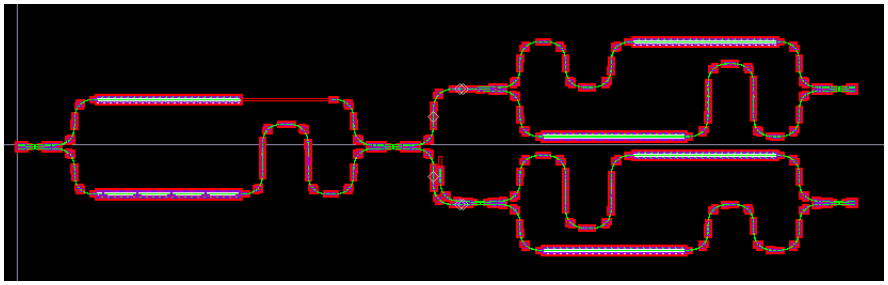
RX Fiber – 100Gb

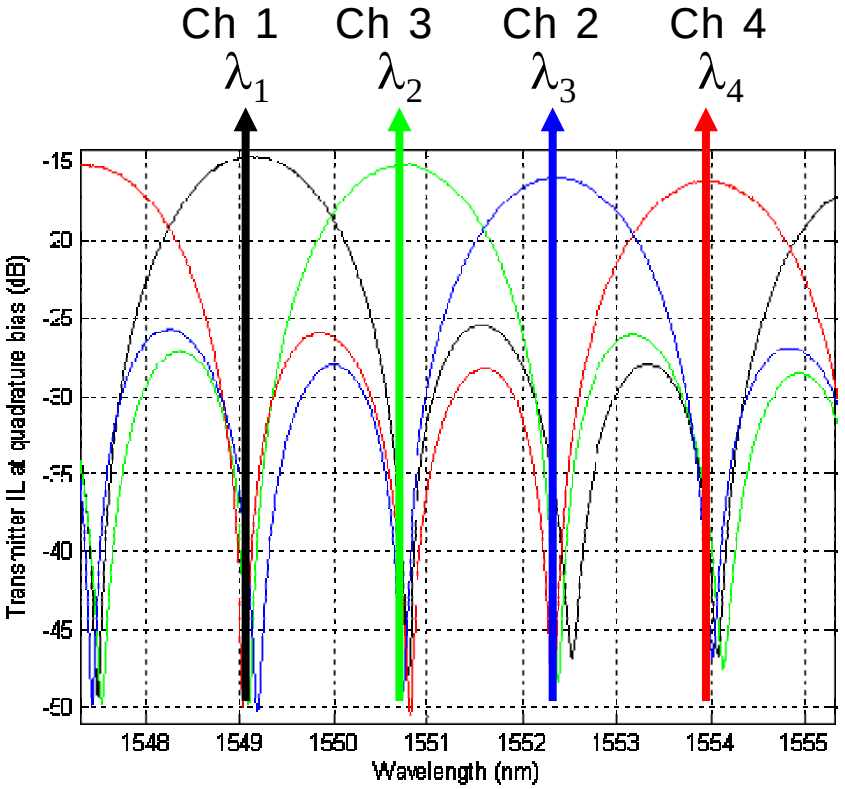
Snapshot of fabricated Pulsar die



Single-chip 40 Gb/s transceiver

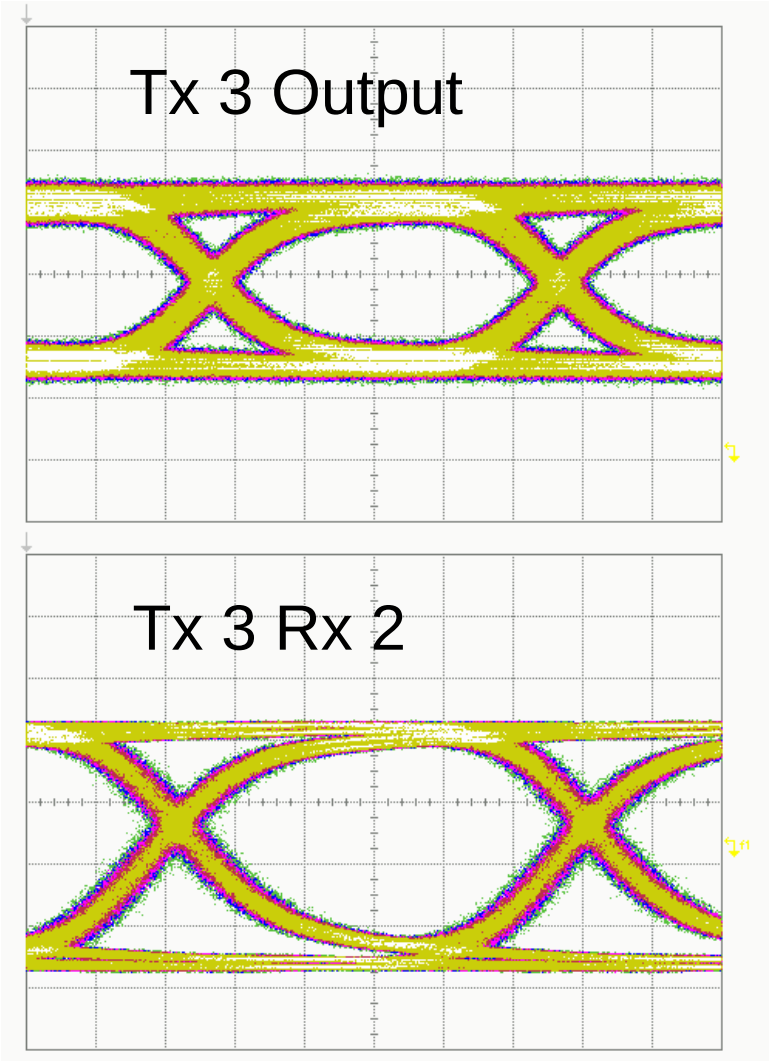
WDM mux/demux





- IL = 1.5dB
- Crosstalk ~20dB
- Bias and Control algorithm implemented off-chip

Results



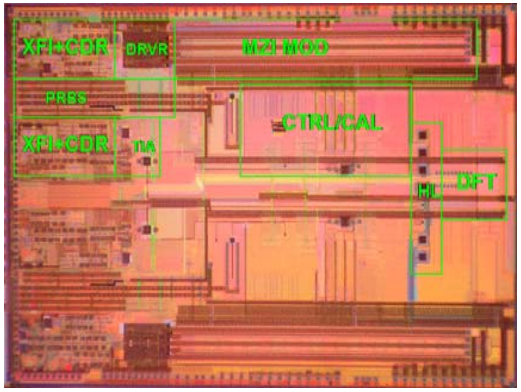
Can we do a 10Tb transceiver in a 1cm die? (That's 1000 10Gb TRXs, each 316x316µm!)

Total Area (mm²):	0.1000
Modulator	0.0036 (3.6%)
Demux:	0.0009 (1%)
Mux:	0.0009 (1%)
Detector:	0.0001 (.1%)
Optical Routing:	0.0050 (5%)
---	---
Area remaining for transceiver electronics	0.0886 (89%)

Luxtera has demonstrated the optics for a 10Tb transceiver in a 1cm² die

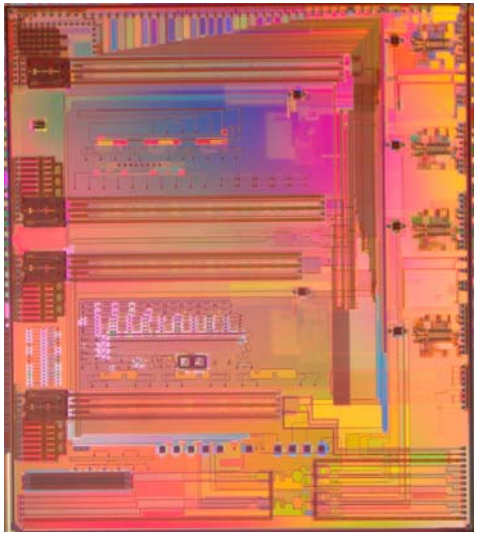
Conclusion: CMOS Photonics Chips Are Working

Aurora



Two independent 10Gb transceivers on a single die (contains complete PHY circuitry)

Pulsar



A single 40Gb WDM transceiver
4λ x 10Gb
(PMD circuits only)

Conclusions

- DARPA EPIC Program has already been a success -- Silicon Photonics Technology is working – currently sampling to customers
- Technology offers the performance of optics, at the price of copper
- There are many technical advantages for silicon photonics to achieve low cost
  - CMOS Manufacturing
  - Wafer scale testability of optics and electronics
  - Built-In Self Test
  - Simplified packaging approach
  - Many channels can be put in a single package
- Longwave (1300-1600nm), single-mode fiber will become the lowest cost alternative